大规模时域巡天：机遇与挑战

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2023/07/04

大纲

- 测光时域巡天的过去、现在与未来
- **时域巡天下的新机遇**
- 时域巡天的挑战：高精度测光
- 时域巡天的挑战：变源瞬变源快速探测和分类

时域巡天下的新机遇

自然基金委《天文学十四五及中长期规划》景益鹏+

多信使天文学：使用引力波、中微子、宇宙线等非电磁手段来研究致密天体性质、丈量宇宙时空、追踪剧烈天体物理过程、检验基本物理规律

时域天文学：采用多波段、多时标方式研究动态宇宙，通过重复观测来揭示宇宙中各类天体的变化，发现和探索新天体、揭示未知的新现象、新规律

行星大科学：关乎生命起源的行星大科学，是集系外行星、太阳系行星、天体生物学、天体化学、地质学研究方法于一体的高度交叉学科，旨在探索行星与生命的起源和演化

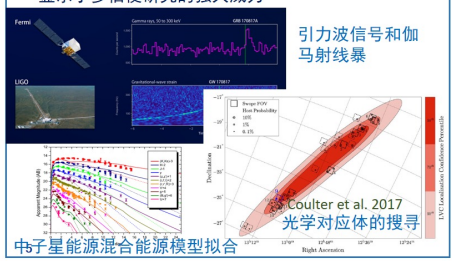
多波段、手段联合观测：不同侧面、不同类型天体更加全面的信息

大天区面积深度巡天：覆盖尽可能多的天体类型和数量

高频率采样、长期持续监测：暂现源和变源的长期/短时标的变化特点

引力波暴电磁对应体：

- 2017年，人类再次从一对中子星的并合事件中，首次实现了引力波和多波段电磁波的联合探测
- 有力推动了短伽马射线暴起源和宇宙中超铁元素（如金、银、铂等）起源等重大科学问题的解决，显示了多信使研究的强大威力



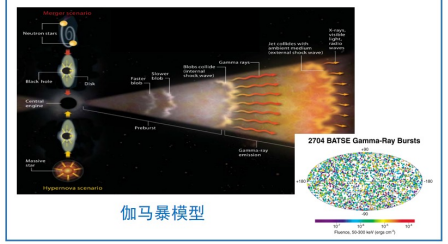
引力波信号和伽马射线暴

光学对应体的搜寻

中子星能源混合能源模型拟合

超新星与伽马射线暴：

- 超新星是大质量恒星在演化末期经历的剧烈爆炸，反映恒星演化最后时刻的空间结构和物理性质
- 伽玛射线暴是宇宙中最为剧烈的恒星尺度爆发现象，是研究早期宇宙的探针，可用于探索第一代/早期恒星、早期金属丰度、宇宙再电离等

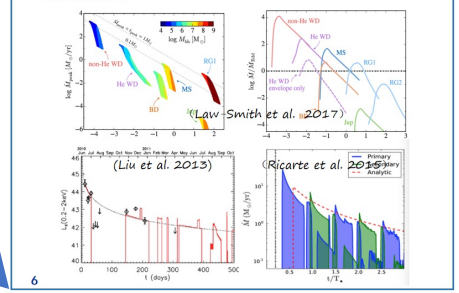


伽马暴模型

\+ + +

黑洞潮汐撕裂恒星事件（TDE）

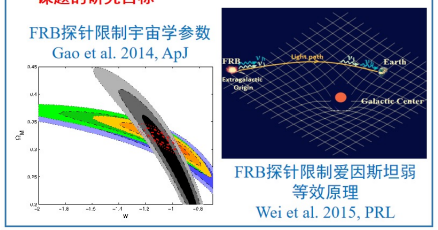
- 发生概率低
- 科学意义显著：理解超大质量黑洞（SMBHs）的起源及其宇宙学成长历史、黑洞吸积物理、引力波多信使观测等



快速射电暴（FRB）

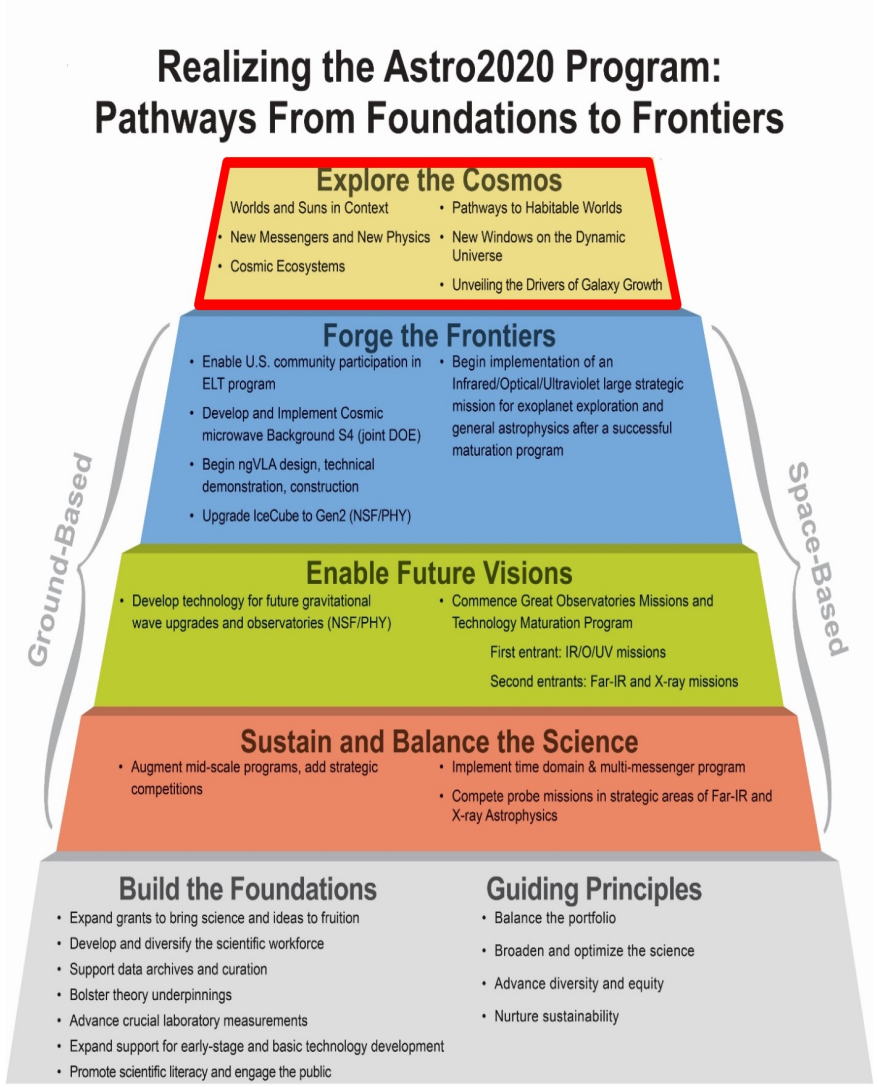
- 一种持续时间仅为数毫秒的爆发性、脉冲式射电辐射天文现象，瞬时辐射流量可达数十央斯基（Jy）
- 全新的天体物理现象，起源未知
- 是从无线电到高能伽马射线，甚至中微子、引力波天文台的探测对象，是从时域天文学到干涉成像多课题的研究目标

FRB探针限制宇宙学参数
Gao et al. 2014, ApJ



FRB探针限制爱因斯坦弱等效原理
Wei et al. 2015, PRL

时域巡天下的新机遇



Priority Area: Pathways to Habitable Worlds

We are on a path to exploring worlds resembling Earth and answering the question: "Are we alone?" The task for the next decades will be finding the easiest of such planets to characterize, and then studying them in detail, searching for signatures of life.

系外行星及宜居性
宿主恒星活动性
系外行星生命信号

Priority Area: New Windows on the Dynamic Universe

The New Windows on the Dynamic Universe priority area involves using light in all its forms, gravitational waves, and neutrinos to study cosmic explosions on all scales and the mergers of compact objects

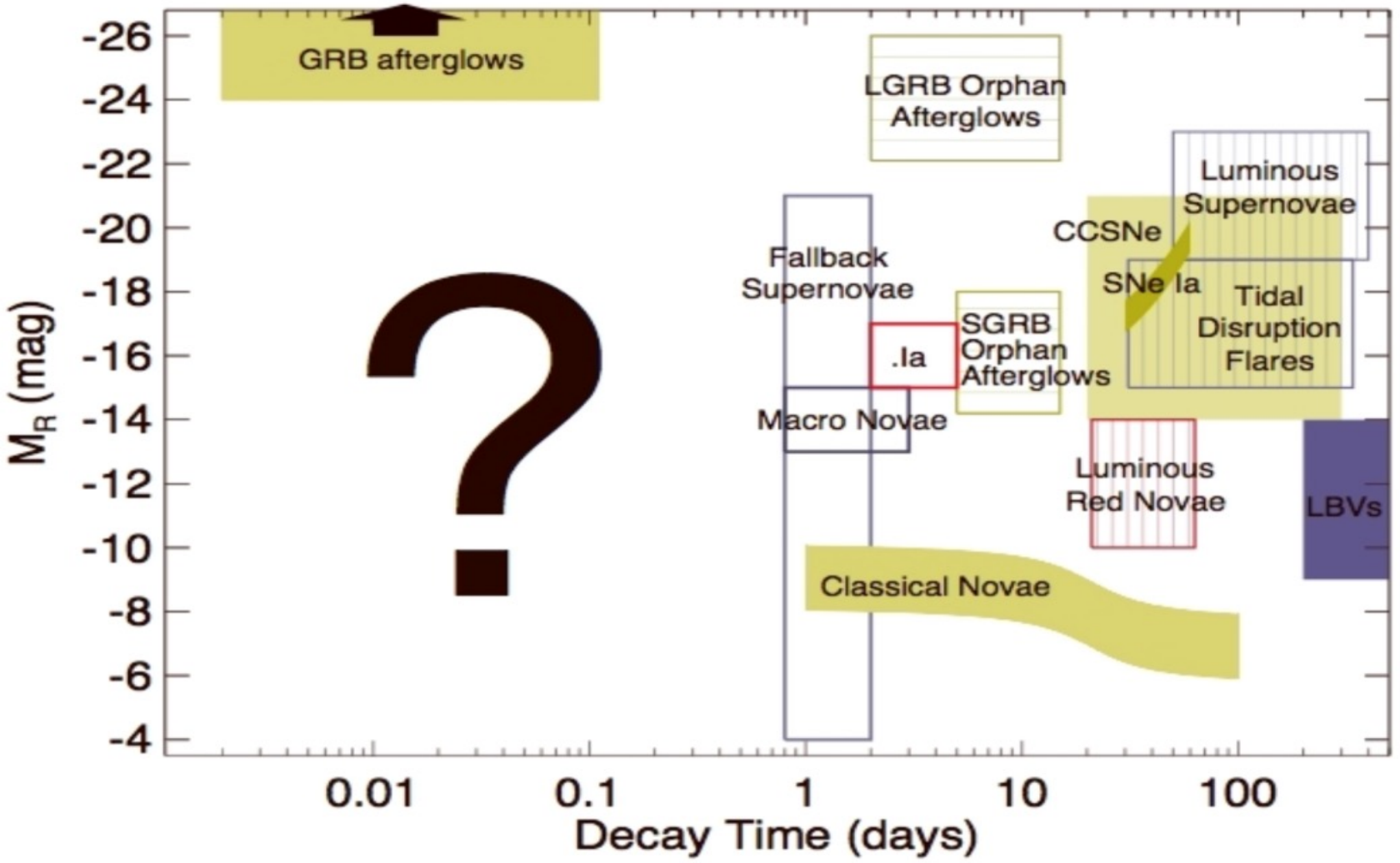
动态宇宙新窗口
多信使多波段
瞬变天体
致密天体

Priority Area: Unveiling the Drivers of Galaxy Growth

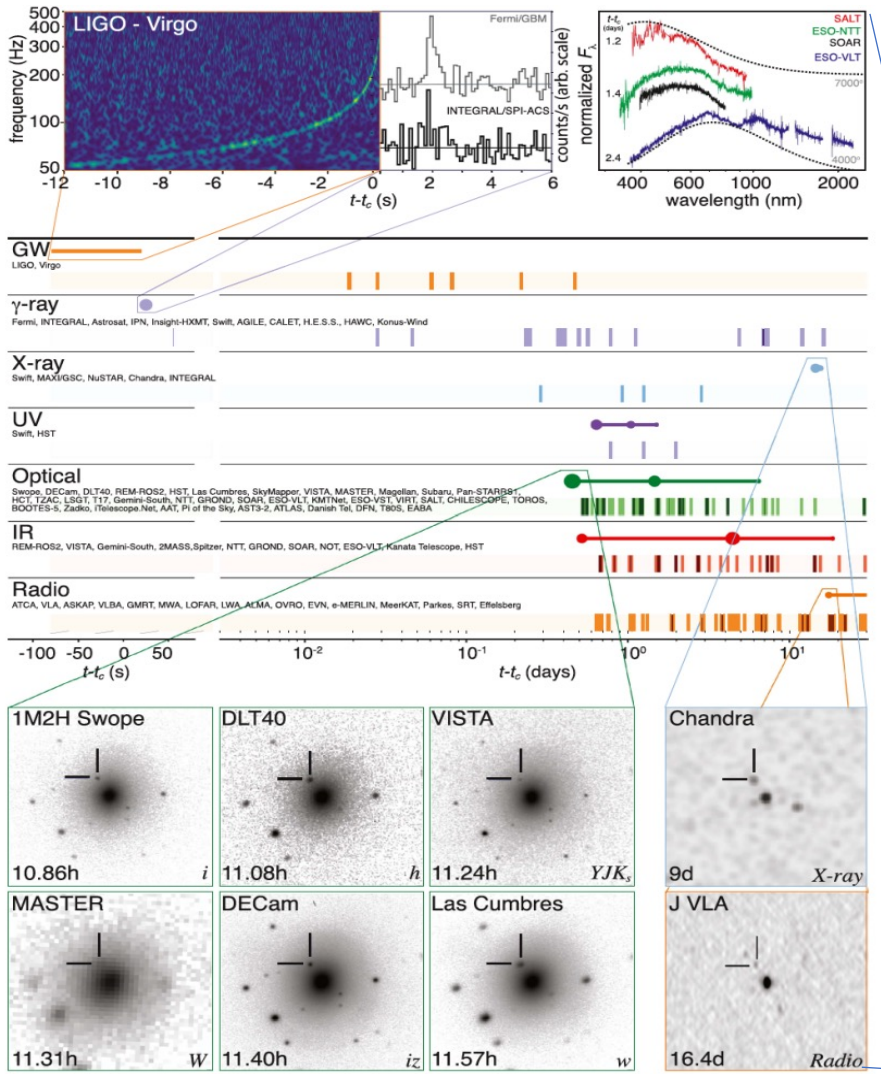
The priority area involves unveiling the drivers of galaxy growth, focusing on processes affecting galactic scales

驱动星系生长
黑洞星系共同
演化等

时域巡天下的新机遇

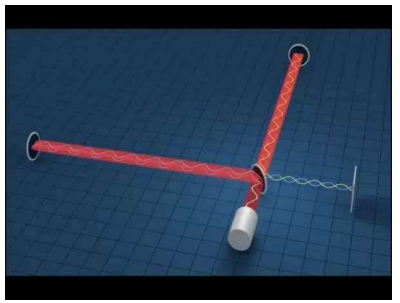

GRB afterglows
LGRB Orphan Afterglows
Luminous Supernovae
CCSNe
Fallback Supernovae
SNe Ia
Tidal Disruption Flares
SGRB Orphan Afterglows
.Ia
Macro Novae
Luminous Red Novae
LBVs
Classical Novae
?
M_R (mag)
-26
-24
-22
-20
-18
-16
-14
-12
-10
-8
-6
-4
0.01
0.1
1
10
100
Decay Time (days)

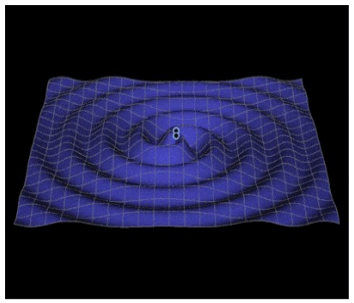
时域巡天下的新机遇

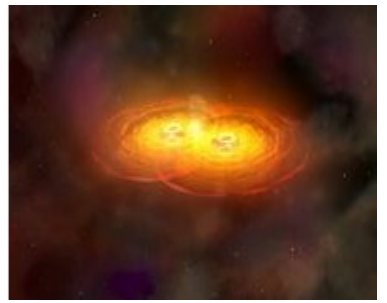


引力波探测获2017年
诺贝尔物理奖

->引力波**天文学**：致密天体并合之电磁对应体







GW170817的电磁对应体观测

❑光学发现：11小时后探测到←1米Swope巡天

❑触发后随光学光谱：1天之后获取

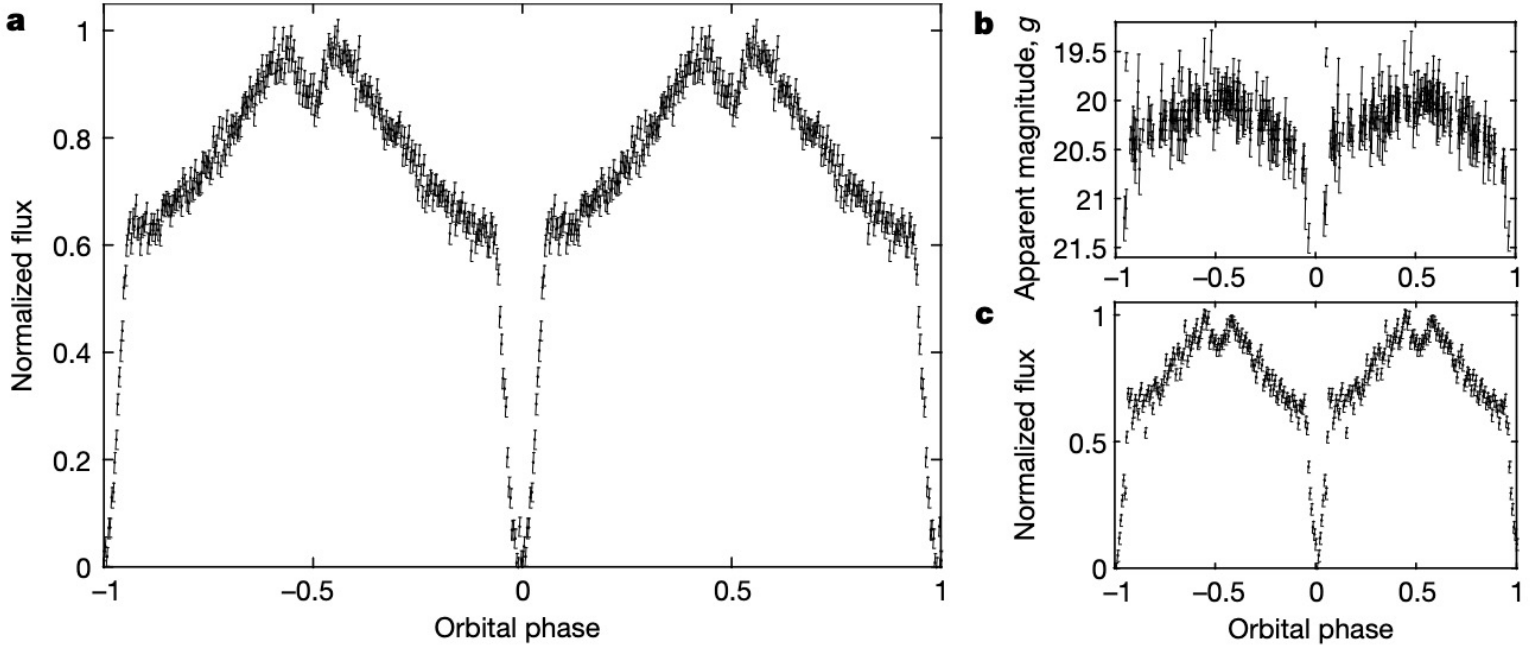
❑探测到后期光变和光谱可以由中子星重元素衰变解释，但反应更关键物理的早期信息被丢失，因此无法区分最核心追求的致密天体模型！

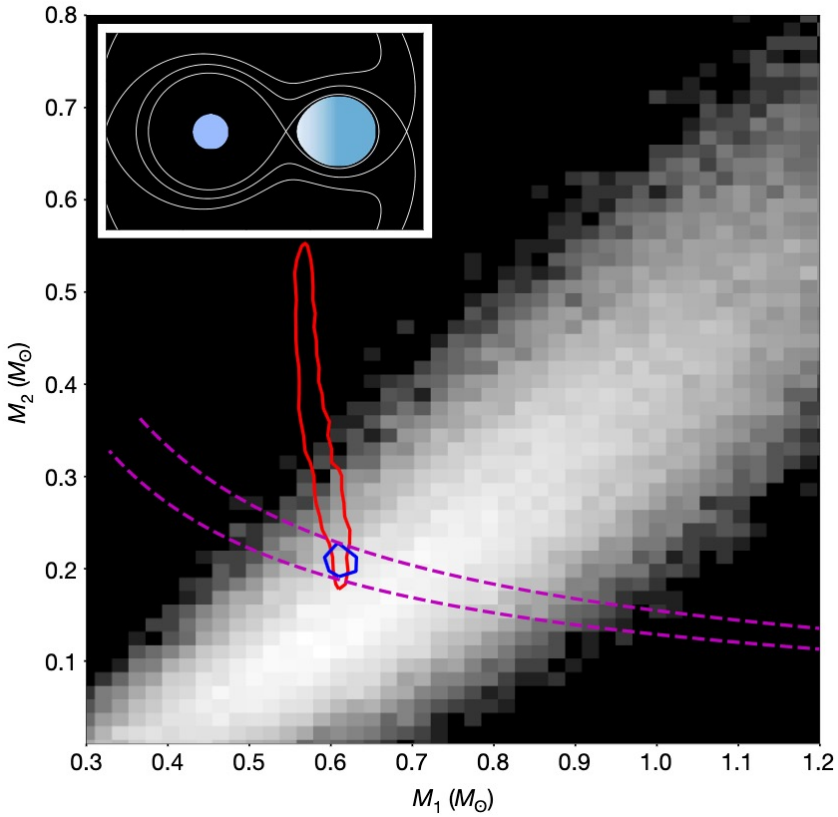
❑问题：需要五个小时内的极早期光变来区分模型！

时域巡天下的新机遇

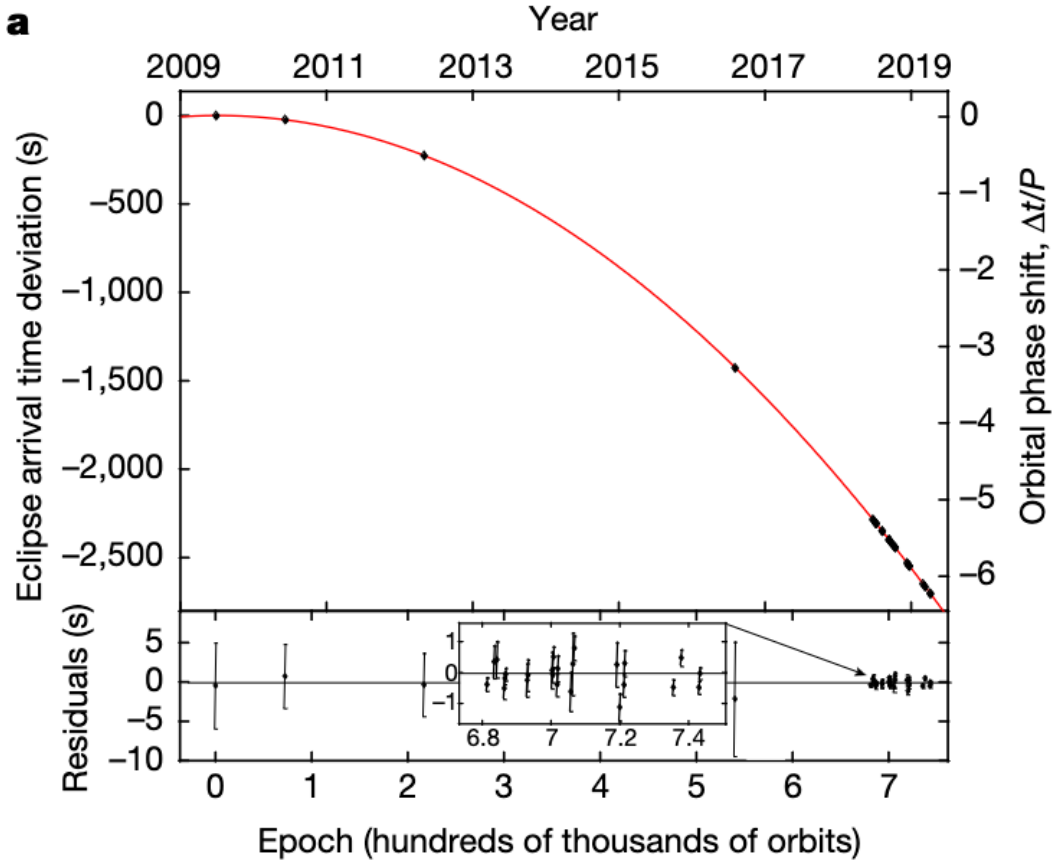
General relativistic orbital decay in a seven-minute-orbital-period eclipsing binary system

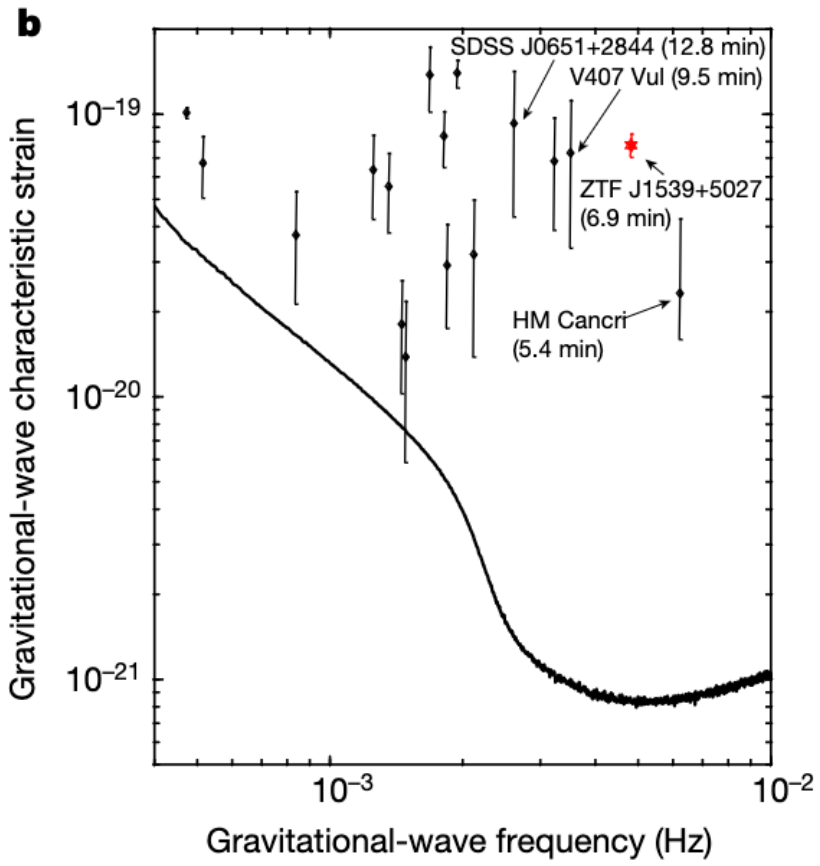
Kevin B. Burdge[1]*, Michael W. Coughlin[1], Jim Fuller[1], Thomas Kupfer[2], Eric C. Bellm[3], Lars Bildsten[2,4], Matthew J. Graham[1], David L. Kaplan[5], Jan van Roestel[1], Richard G. Dekany[6], Dmitry A. Duev[1], Michael Feeney[6], Matteo Giomi[7], George Helou[8], Stephen Kaye[6], Russ R. Laher[8], Ashish A. Mahabal[1], Frank J. Masci[8], Reed Riddle[6], David L. Shupe[8], Maayane T. Soumagnac[9], Roger M. Smith[6], Paula Szkody[3], Richard Walters[6], S. R. Kulkarni[1] & Thomas A. Prince[1]



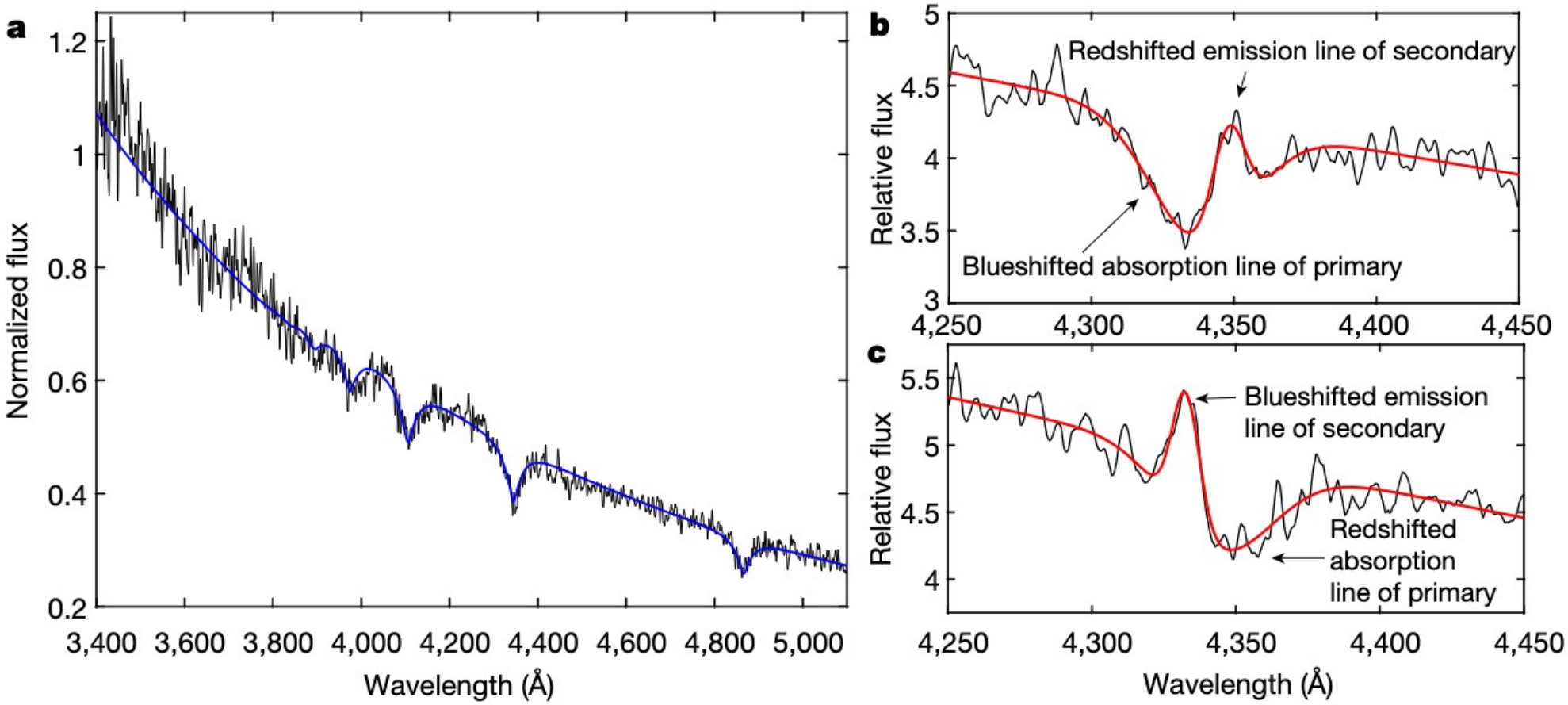


时域巡天下的新机遇


a
Year
2009
2011
2013
2015
2017
2019
Eclipse arrival time deviation (s)
0
−500
−1,000
−1,500
−2,000
−2,500
Orbital phase shift, Δt/P
0
−1
−2
−3
−4
−5
−6
Residuals (s)
5
0
−5
−10
1
0
−1
6.8
7
7.2
7.4
0
1
2
3
4
5
6
7
Epoch (hundreds of thousands of orbits)

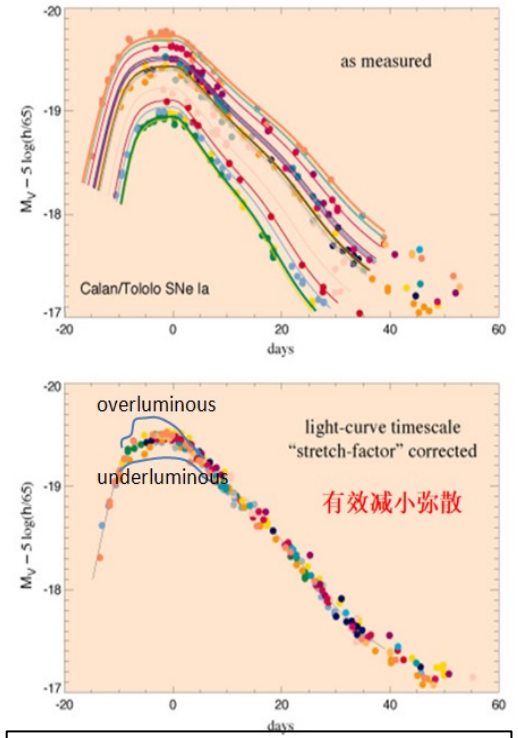

b
SDSS J0651+2844 (12.8 min)
V407 Vul (9.5 min)
ZTF J1539+5027
(6.9 min)
HM Cancri
(5.4 min)
Gravitational-wave characteristic strain
10−19
10−20
10−21
10−3
10−2
Gravitational-wave frequency (Hz)

时域巡天下的新机遇

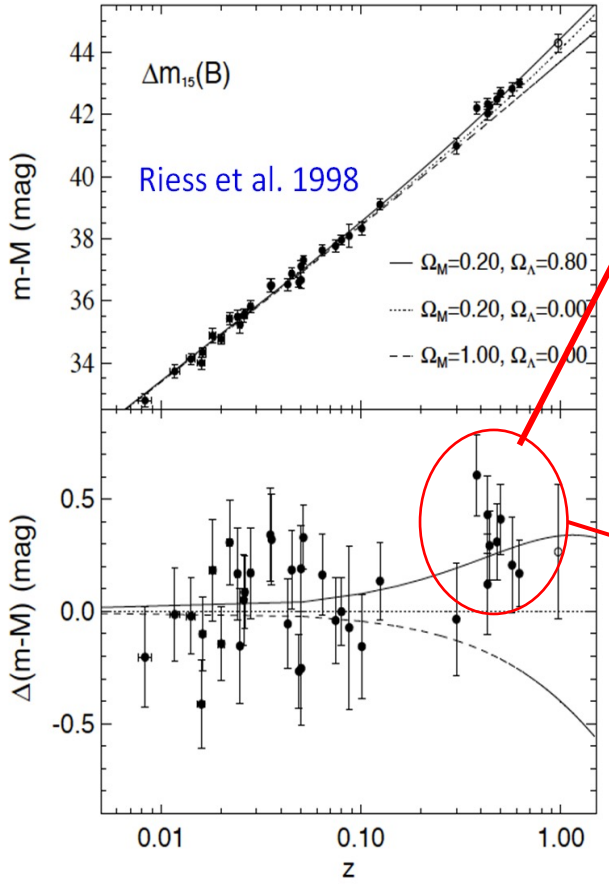

a
Normalized flux
1.2
1
0.8
0.6
0.4
0.2
3,400 3,600 3,800 4,000 4,200 4,400 4,600 4,800 5,000
Wavelength (Å)
b
Relative flux
5
4.5
4
3.5
3
Redshifted emission line of secondary
Blueshifted absorption line of primary
4,250 4,300 4,350 4,400 4,450
c
Relative flux
5.5
5
4.5
4
Blueshifted emission line of secondary
Redshifted absorption line of primary
4,250 4,300 4,350 4,400 4,450
Wavelength (Å)

时域巡天下的新机遇

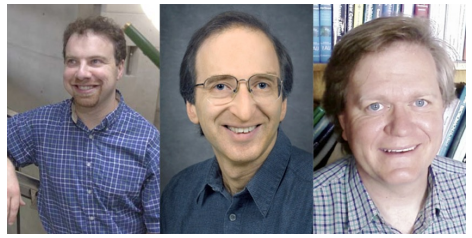
Ia型超新星和宇宙学



SNIa：可标准化烛光



SNIa看起来比纯物质膨胀宇宙预想的暗！



2011年诺贝尔奖物理学

宇宙在加速膨胀

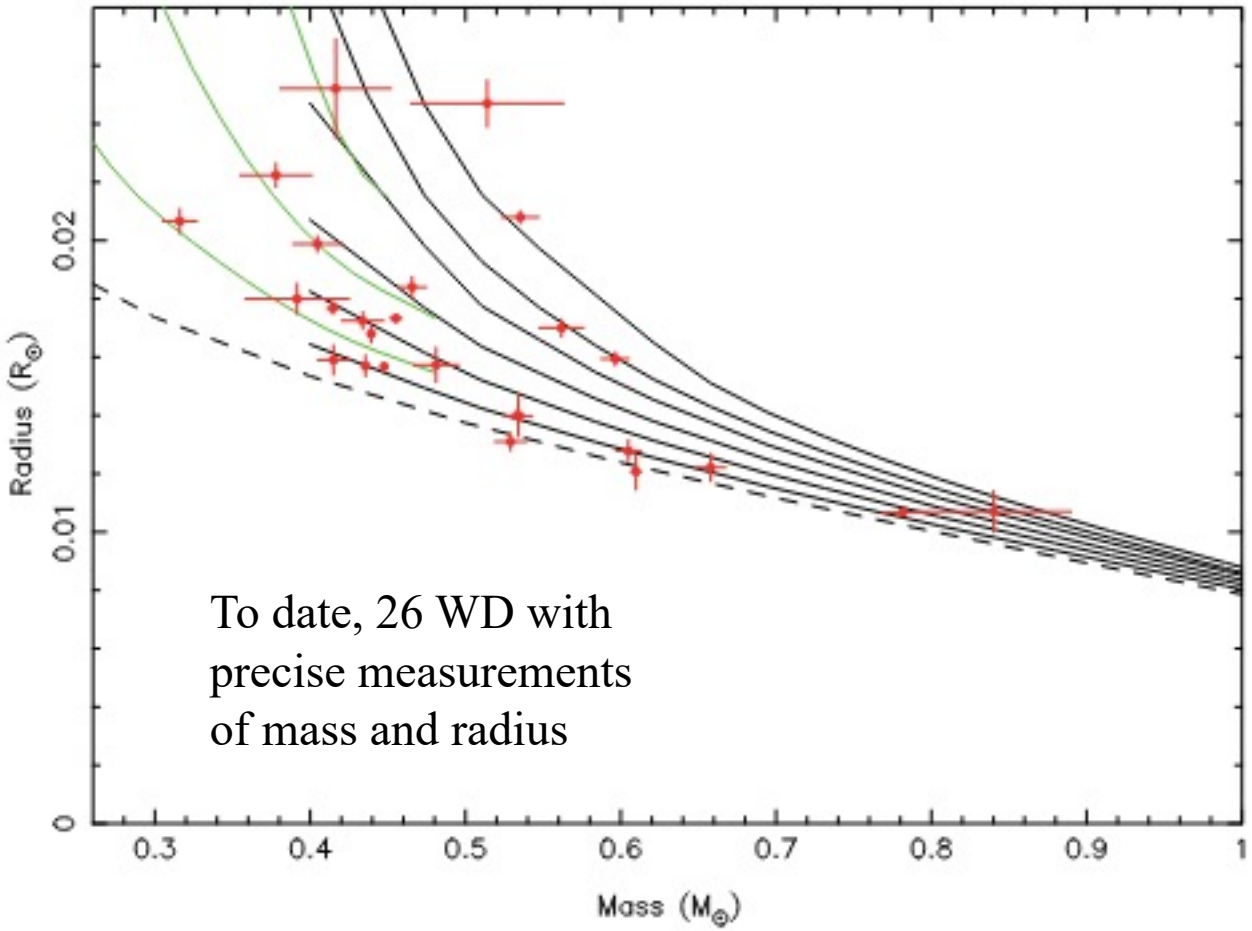
→存在“暗能量”

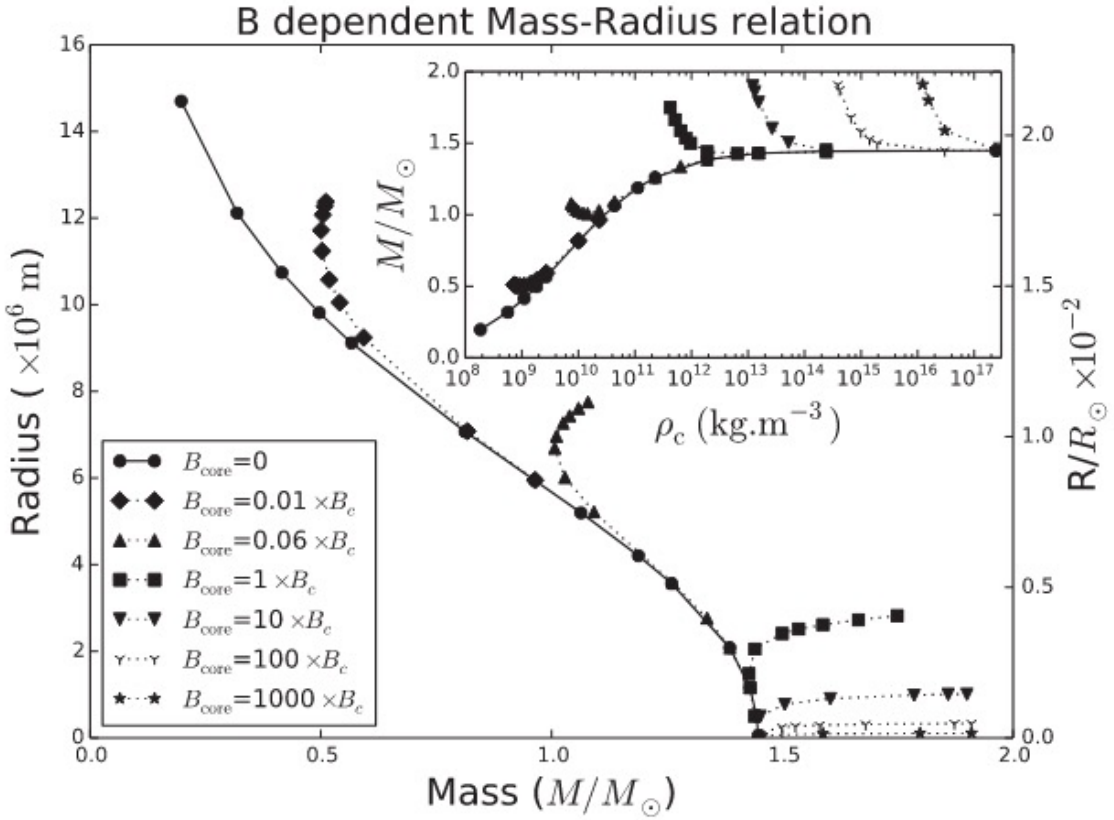
存在问题：

- ❑ 黄金样本测距精度差：10%！
- ❑ 选择效应和系统误差不清楚！
- ❑ Ia型超新星前身星和物理本质不确定
  因为缺少超新星爆发极早期信息

时域巡天下的新机遇

白矮星的质量-半径关系





Bera & Bhattacharya 2014

时域巡天下的新机遇

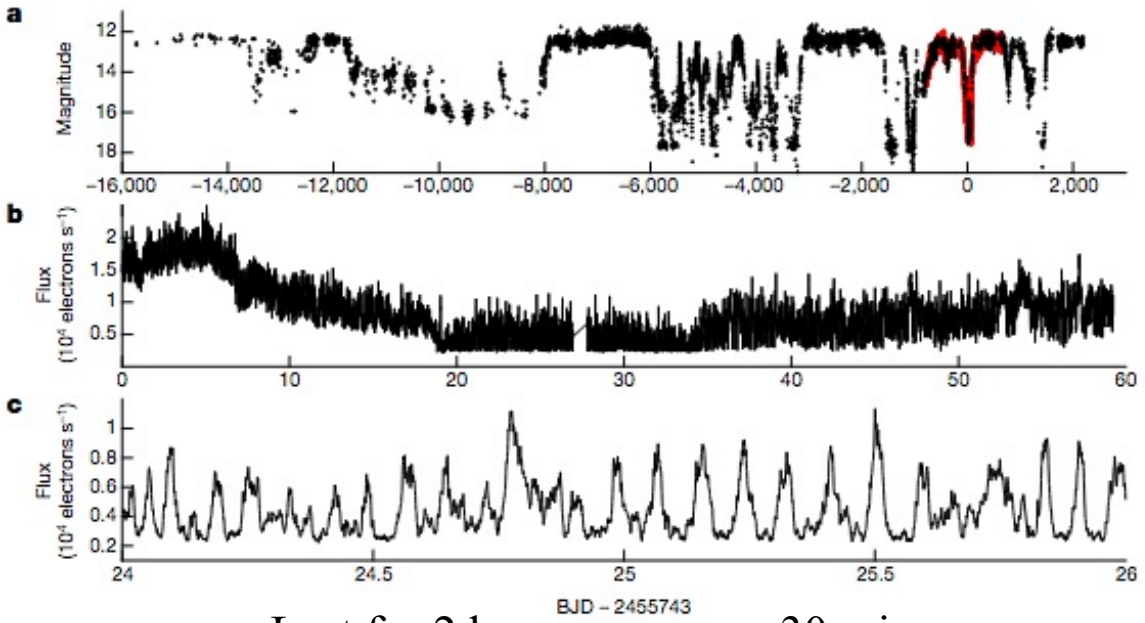
磁场对CV吸积的影响

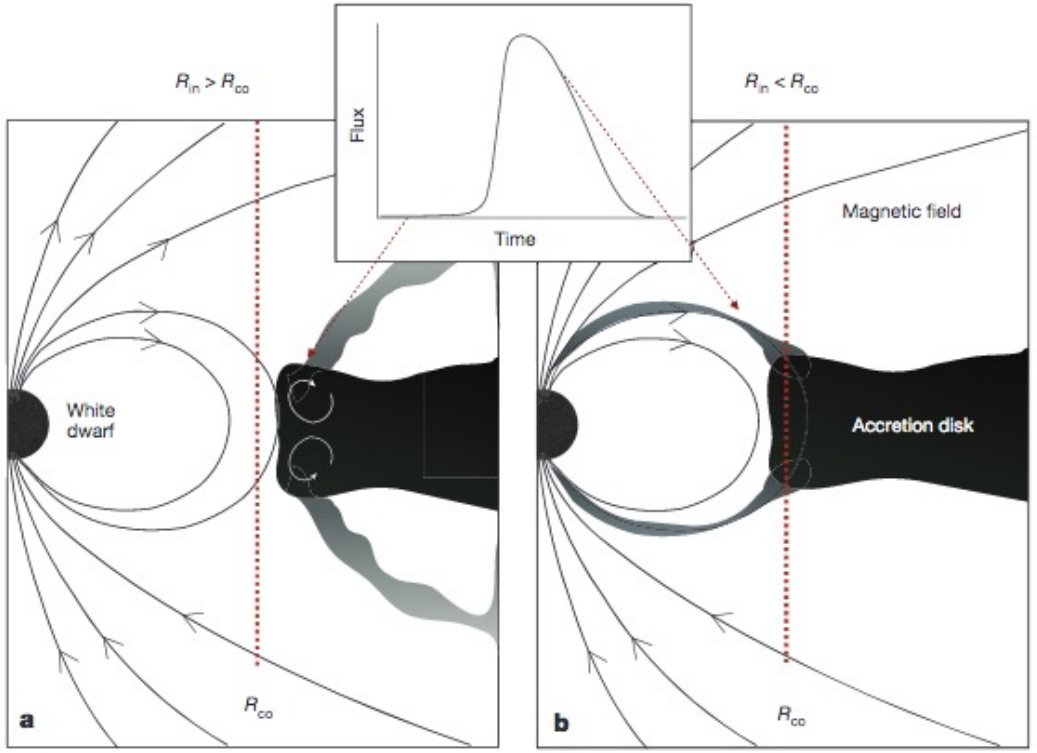
LETTER

doi:10.1038/nature24653

Magnetically gated accretion in an accreting 'non-magnetic' white dwarf

S. Scaringi[1], T. J. Maccarone[2], C. D'Angelo[3], C. Knigge[4] & P. J. Groot[5]





Last for 2 hours per every 30 mins

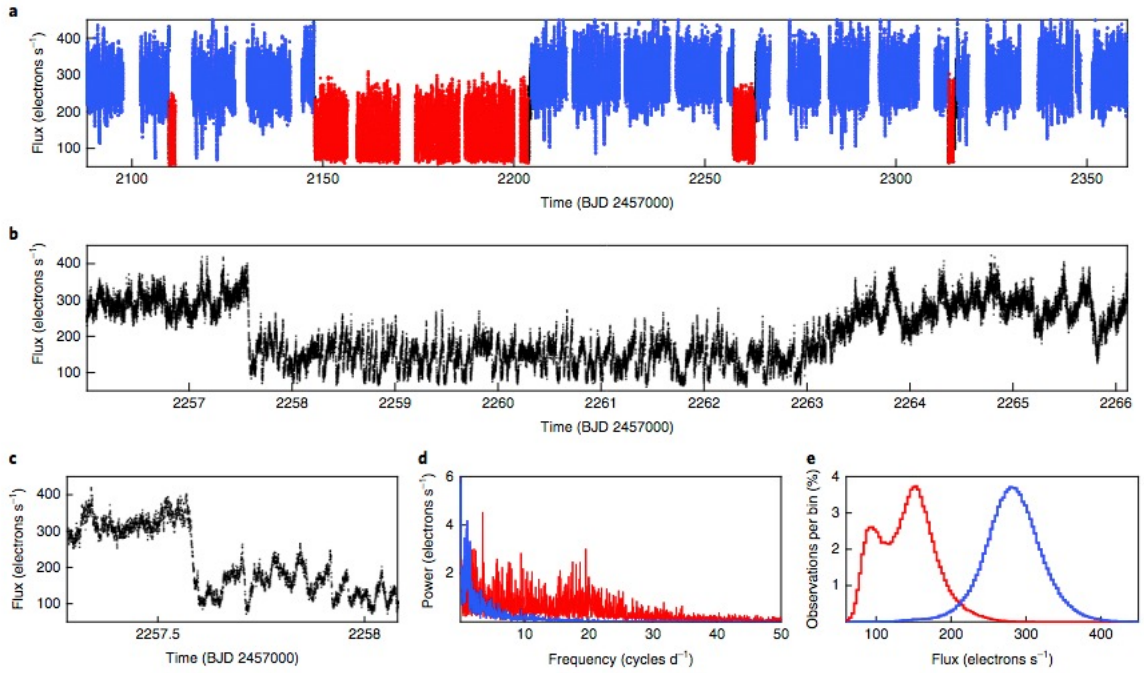
时域巡天下的新机遇

磁场对CV吸积的影响

LETTERS
https://doi.org/10.1038/s41550-021-01494-x
nature astronomy
Check for updates

An accreting white dwarf displaying fast transitional mode switching

S. Scaringi[1]✉, D. de Martino[2], D. A. H. Buckley[3,4,5], P. J. Groot[3,4,6], C. Knigge[7], K. Iłkiewicz[1], C. Littlefield[8,9] and A. Papitto[10]

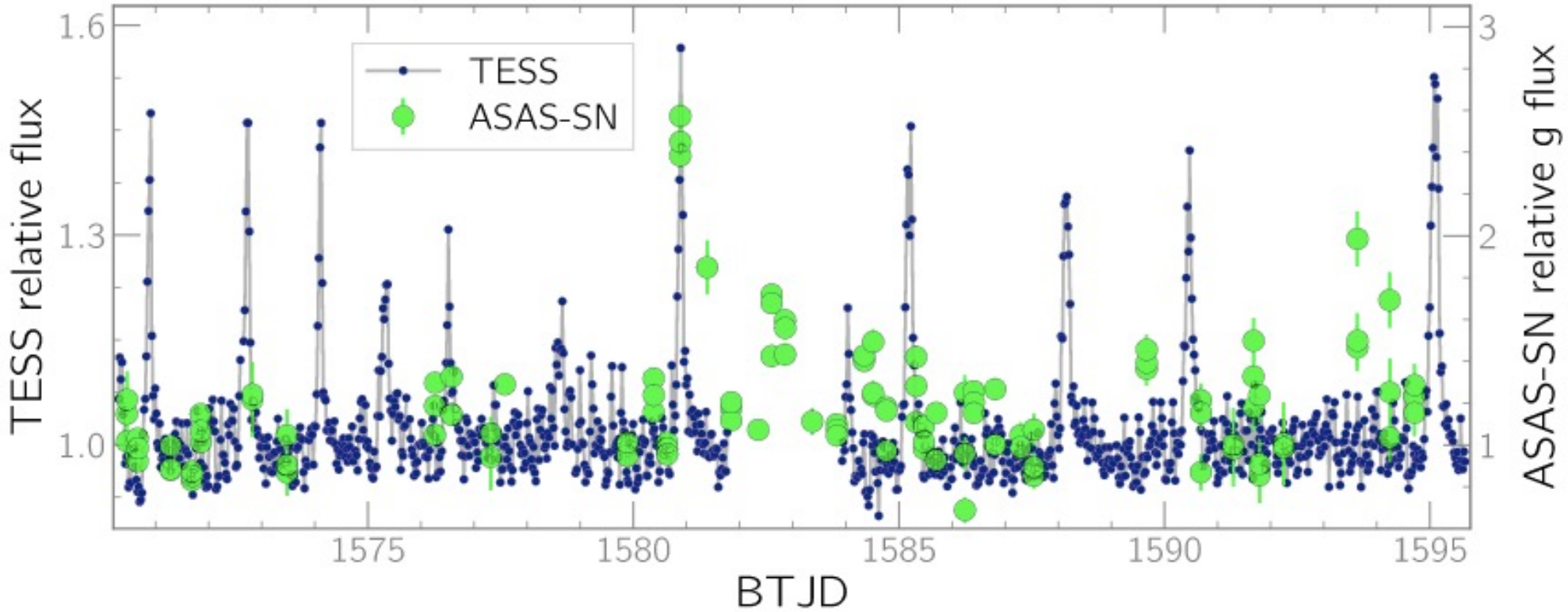


时域巡天下的新机遇

The Astrophysical Journal Letters, 924:L8 (6pp), 2022 January 1 https://doi.org/10.3847/2041-8213/ac4262

Rapid Bursts of Magnetically Gated Accretion in the Intermediate Polar V1025 Cen

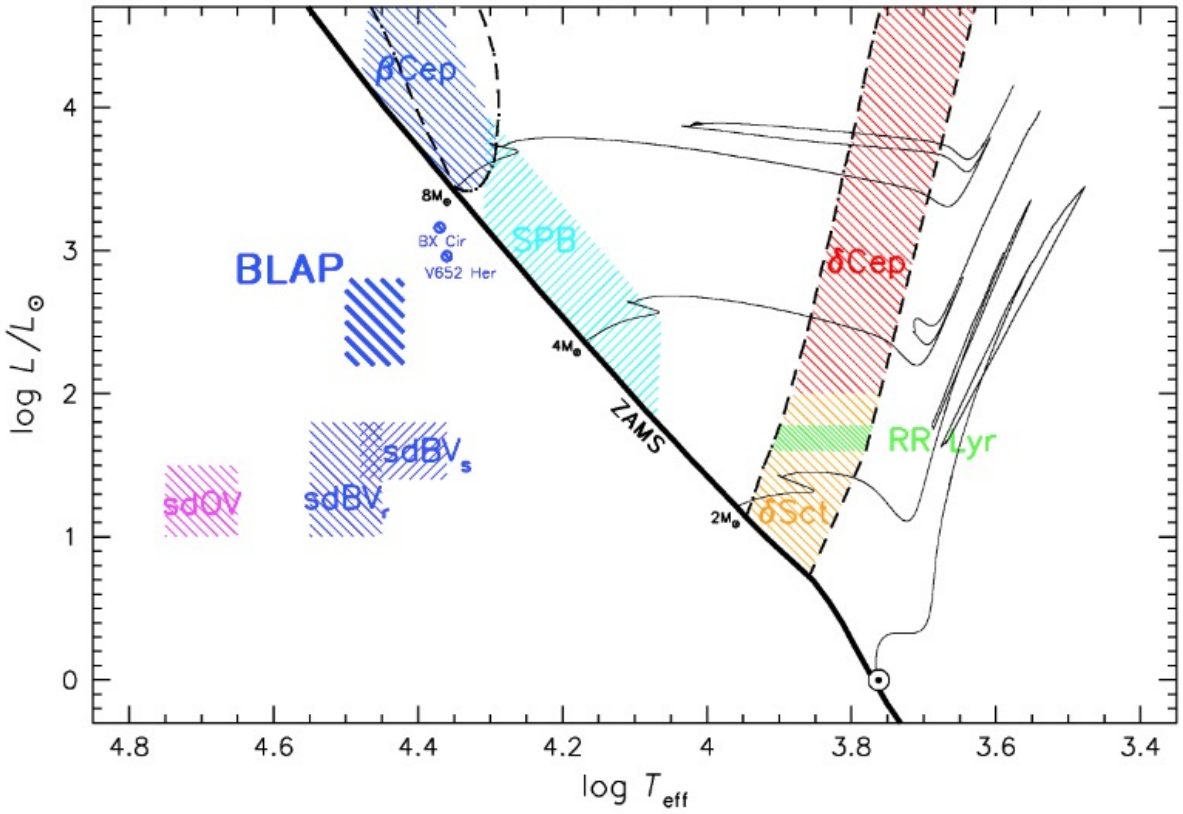
Colin Littlefield[1,2,3], Jean-Pierre Lasota[4,5], Jean-Marie Hameury[6], Simone Scaringi[7], Peter Garnavich[1], Paula Szkody[2], Mark Kennedy[8], and McKenna Leichty[1]

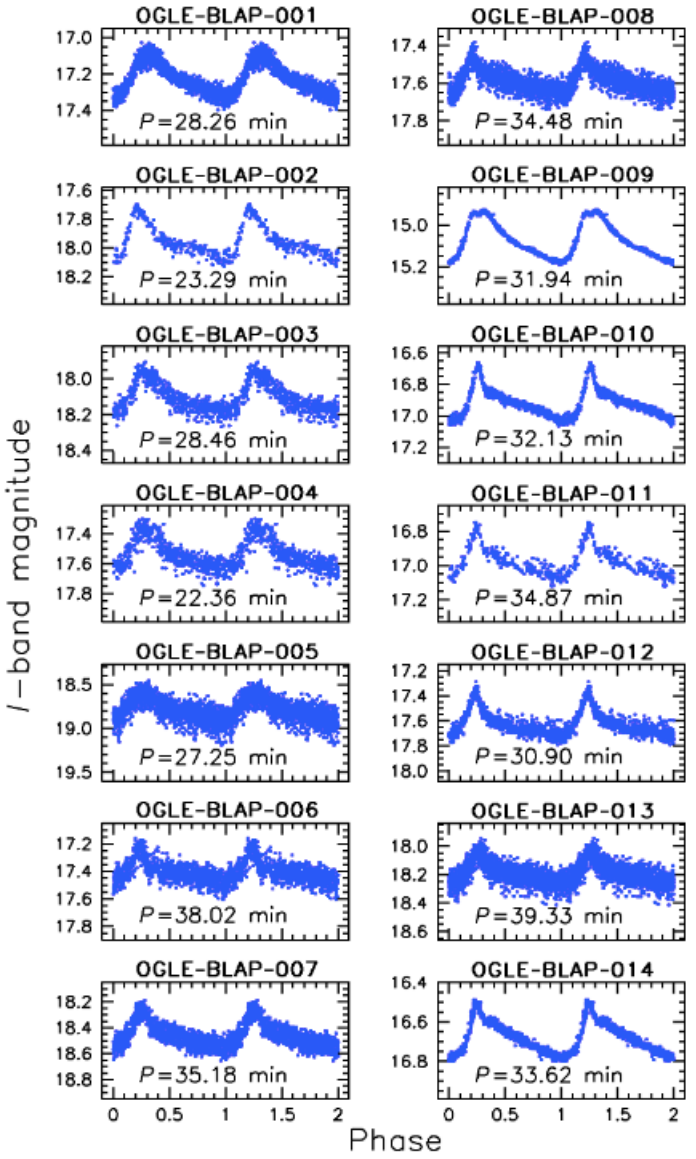


时域巡天下的新机遇

Blue large-amplitude pulsators as a new class of variable stars

Paweł Pietrukowicz[1*], Wojciech A. Dziembowski[1,2], Marilyn Latour[3], Rodolfo Angeloni[4,5,6], Radosław Poleski[1,7], Francesco di Mille[8], Igor Soszyński[1], Andrzej Udalski[1], Michał K. Szymański[1], Łukasz Wyrzykowski[1], Szymon Kozłowski[1], Jan Skowron[1], Dorota Skowron[1], Przemek Mróz[1], Michał Pawlak[1] and Krzysztof Ulaczyk[1,9]





时域巡天下的新机遇

Tsinghua University-Ma Huateng Telescopes for Survey

4*40cm
4k*4k QHY4040 CMOS detector
4.5 sq. deg. with a pixel scale of 1.86”/pixel

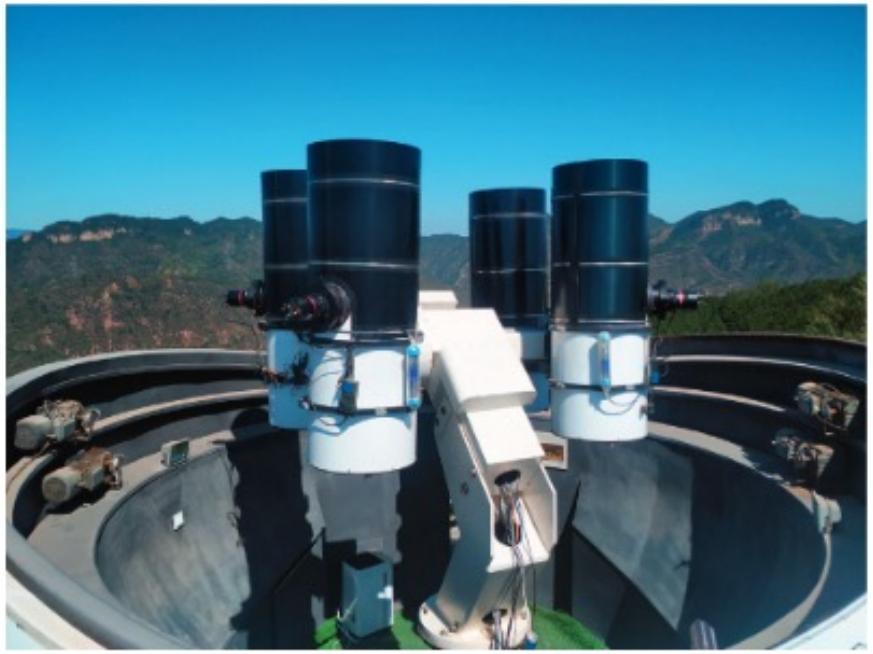
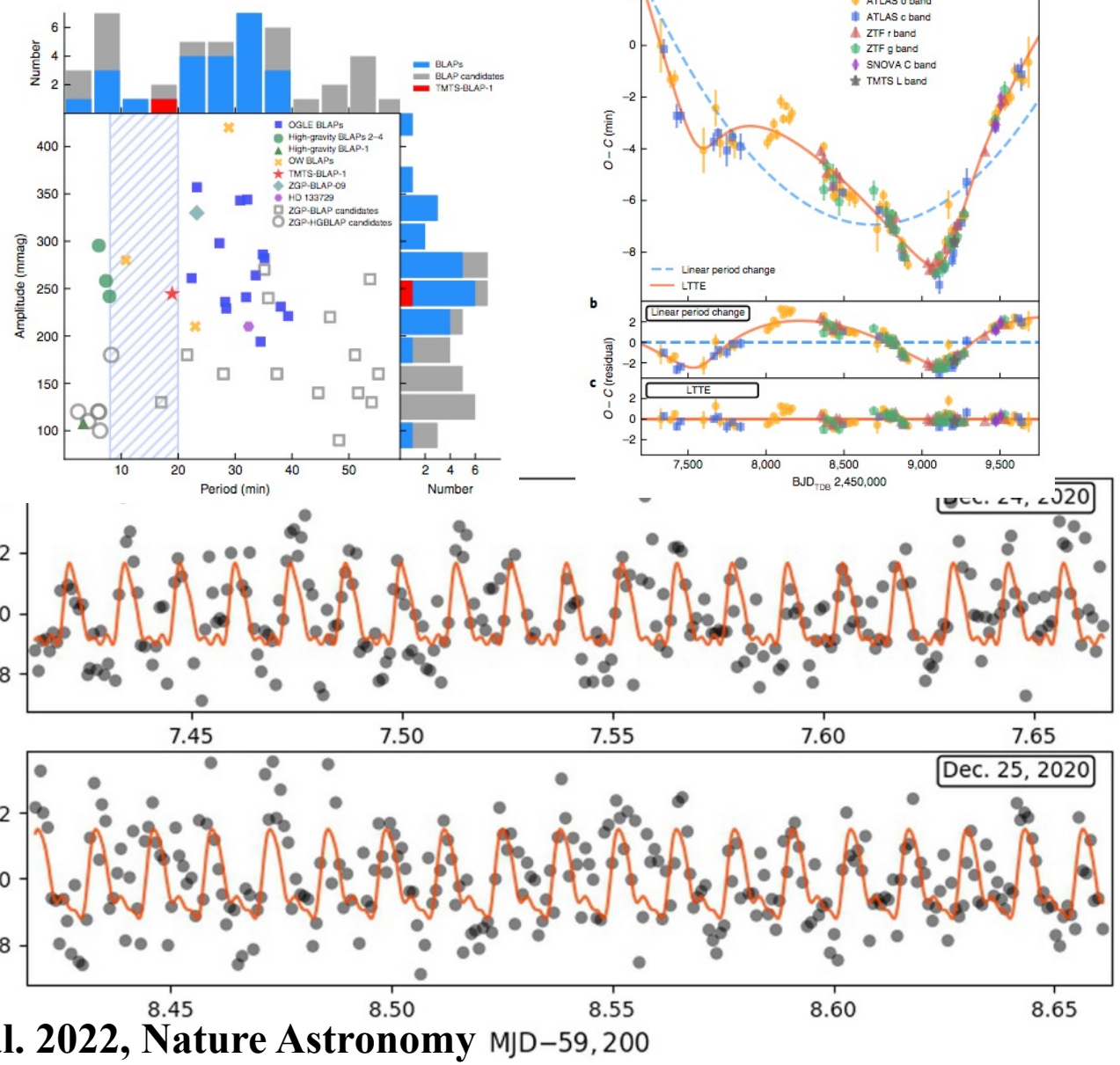


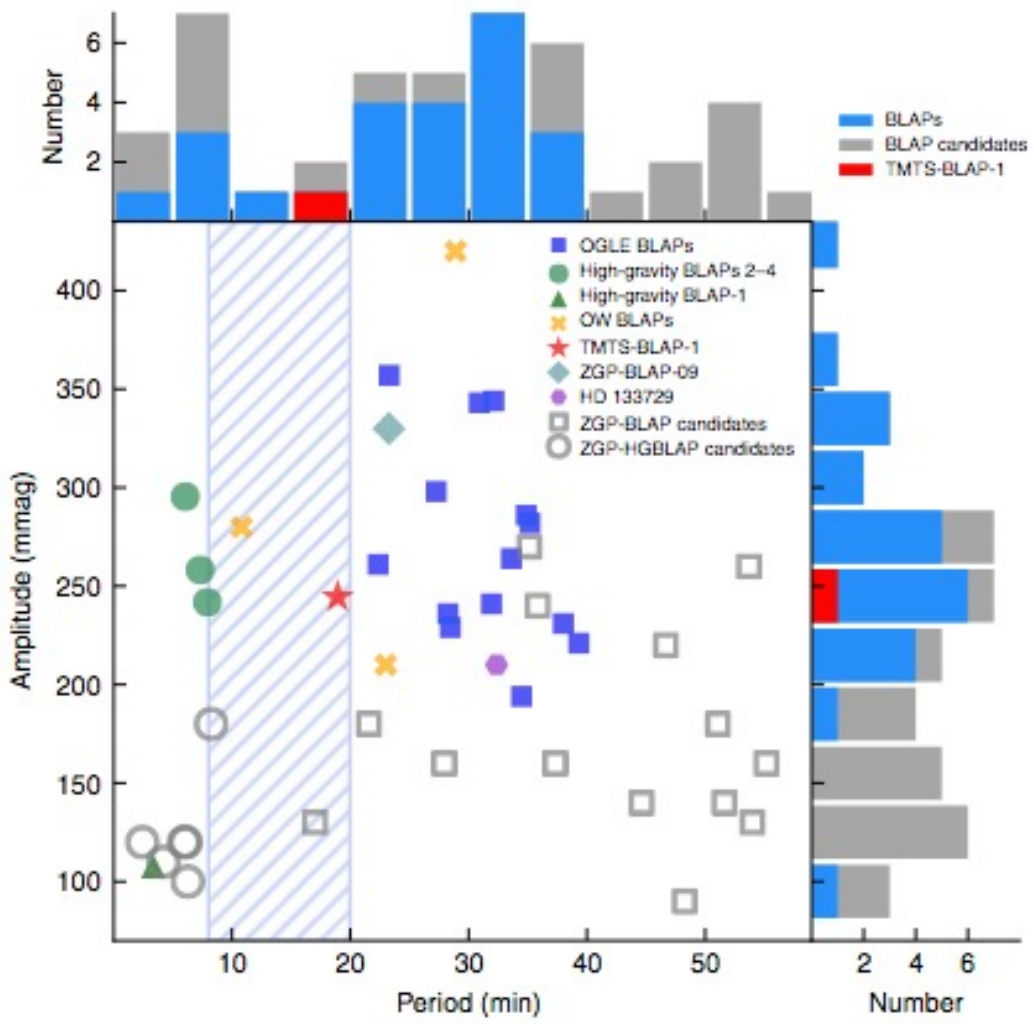
Figure 2. Overview of the TMTS system inside the dome.
(A color version of this figure is available in the online journal.)

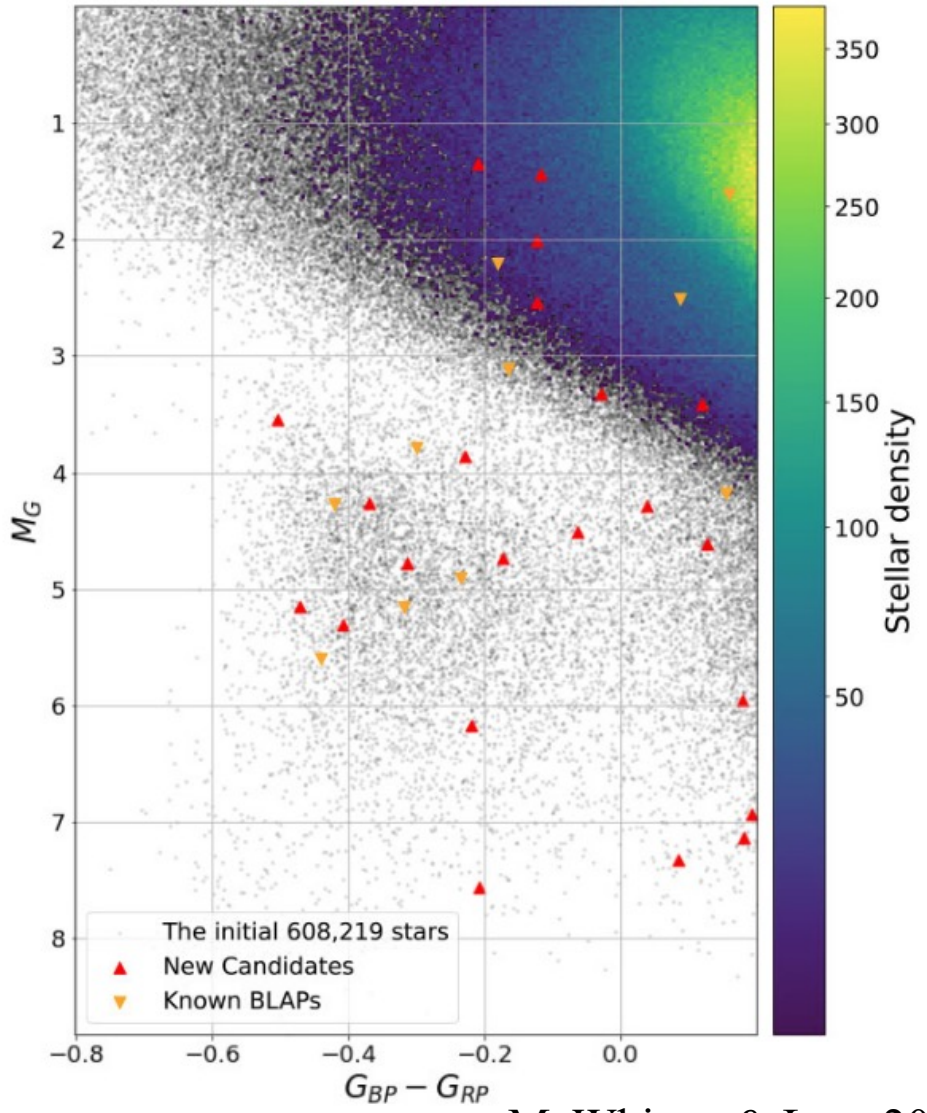
Zhang et al. 2020, PASP, 132, 125001



Lin et al. 2022, Nature Astronomy

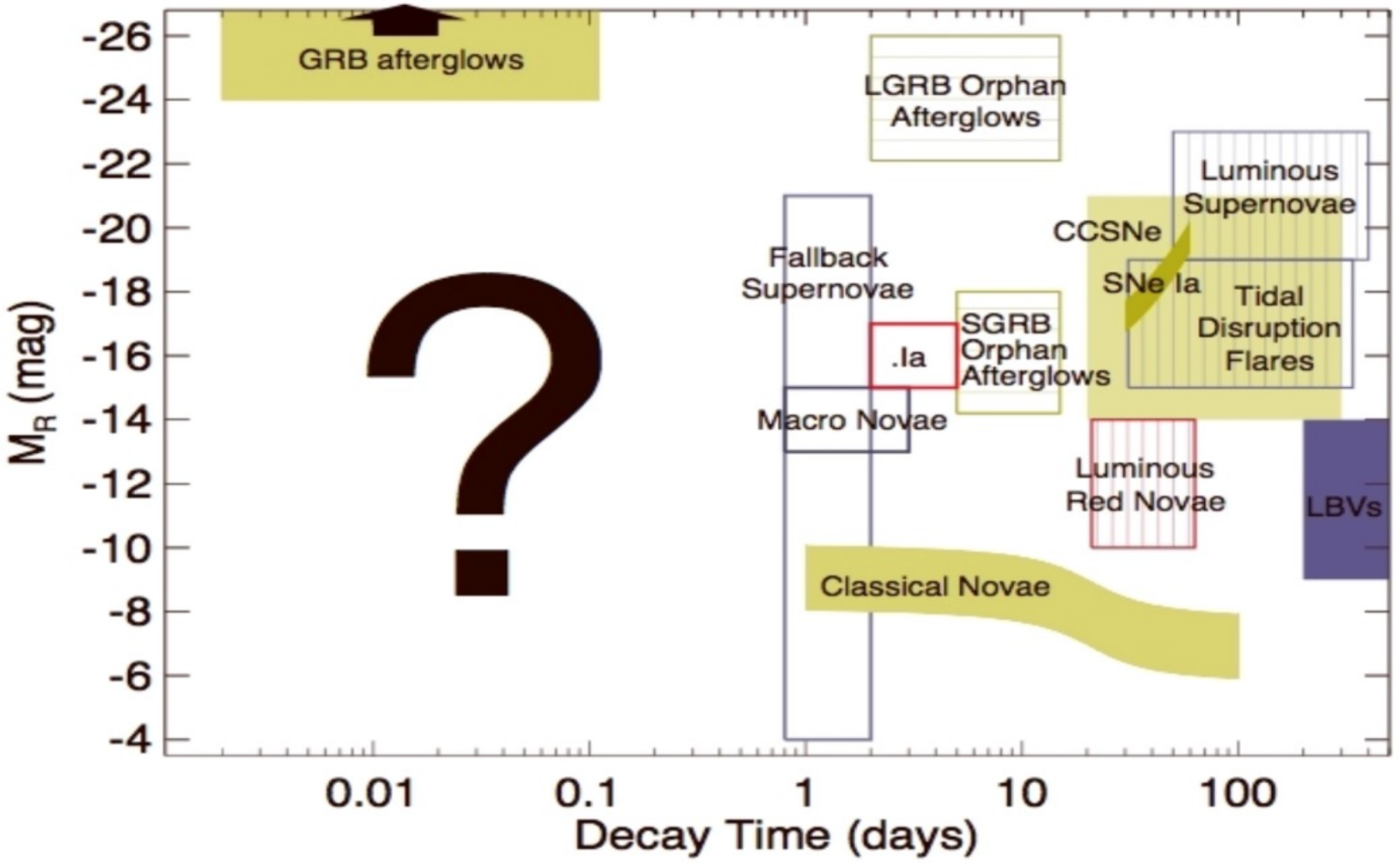
时域巡天下的新机遇



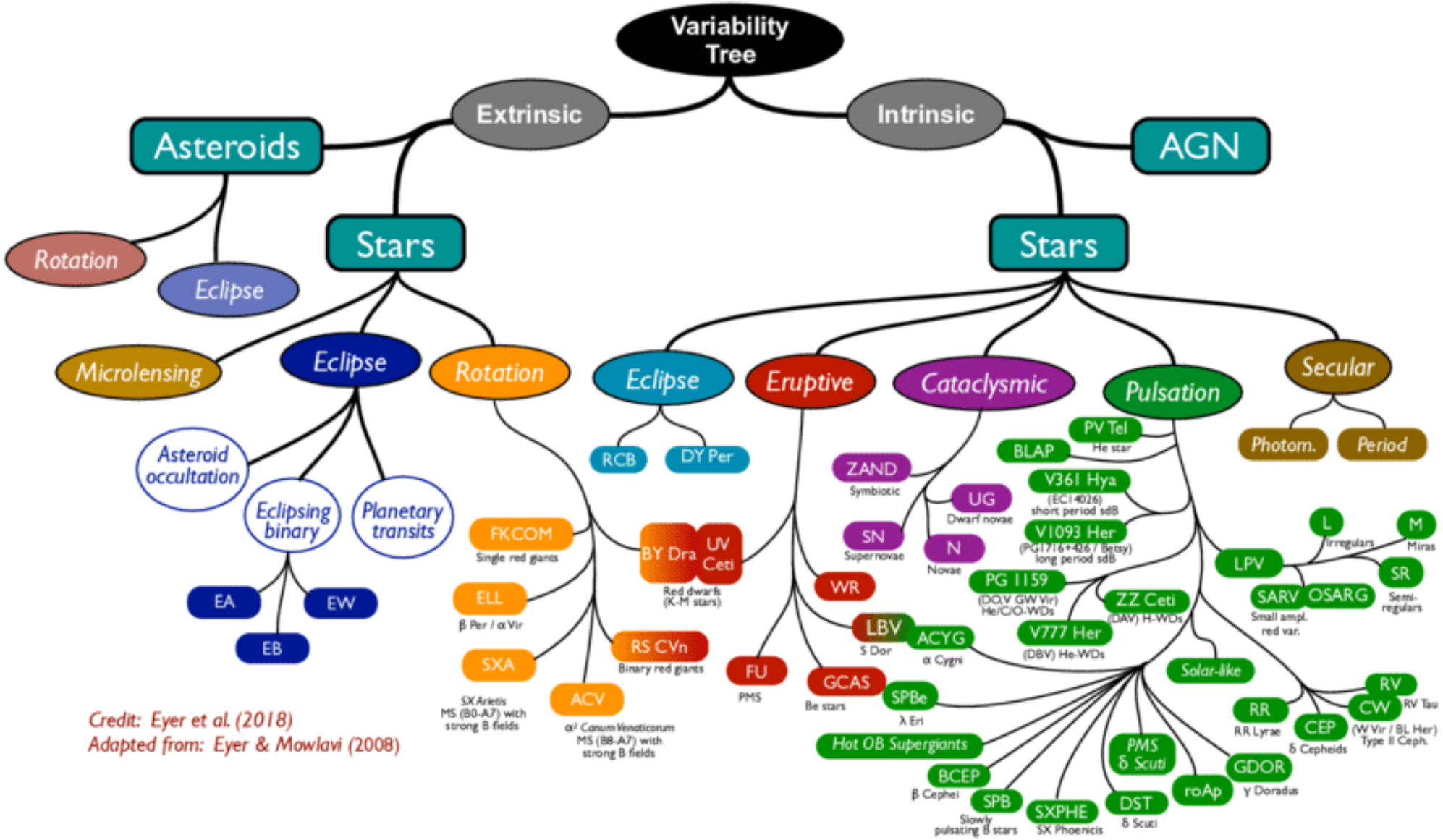


McWhirter & Lam 2022

时域巡天下的新机遇


GRB afterglows
LGRB Orphan Afterglows
Luminous Supernovae
CCSNe
Fallback Supernovae
SNe Ia
Tidal Disruption Flares
SGRB Orphan Afterglows
.Ia
Macro Novae
Luminous Red Novae
LBVs
Classical Novae
?
M_R (mag)
-26
-24
-22
-20
-18
-16
-14
-12
-10
-8
-6
-4
0.01
0.1
1
10
100
Decay Time (days)

时域巡天下的新机遇



Credit: Eyer et al. (2018)
Adapted from: Eyer & Mowlavi (2008)

实践二：

一、用档案数据（如Catalina、ASAS-SN、ZTF等）制作每一类变源的典型不同波段光变曲线

二、将它们画在赫罗图上


谢谢！
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2012.08.22 Nikon D90 + 10-24mm, F3.5, 14x30s, ISO2500
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